Freezing Injury of Root Crops: Beets, Carrots, Parsnips, Radishes, and Turnips

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Freezing Injury of Root Crops: Beets, Carrots, Parsnips, Radishes, and Turnips

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SUMMARY

Beets, carrots, parsnips, radishes, and turnips were frozen for various periods at both 0° and 20° F. Internal and external symptoms of freezing injury, observed immediately after freezing and after thawing at 40° or 70°, are described and illustrated. The keeping quality was determined for each frozen vegetable thawed at 40° and 70°. Data on rate of freezing, weight loss during freezing and thawing, and respiration immediately after freezing are presented for some of the vegetables.

The principal symptom of freezing injury in beets is internal and external watersoaking that appears during freezing and sometimes persists after thawing at 40° or 70° F. Slightly frozen beets kept equally well for 2 days at 40° or 70°. Severely frozen beets softened as they thawed and kept poorly at both temperatures.

Injury in carrots immediately after freezing is identified by lengthwise cracking and by a blistering caused by the formation of ice crystals immediately beneath the surface. A darkened and watersoaked skin was observed after thawing. Weight loss and decay were less in frozen carrots held at 40° than in those held at 70°.

Parsnips were only slightly affected by freezing for up to 3 hours at either 0° or 20° F. Most remained salable after thawing. More severe freezing caused the outer surface and flesh of parsnips to discolor during thawing. Frozen parsnips kept better when thawed and held at 40° than at 70°.

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Radishes rapidly became watersoaked, both internally and externally, when frozen at either 0° or 20° F. During thawing at either 40° or 70°, frozen radishes shriveled and developed sunken areas. Frozen radishes decayed more rapidly at 70° than at 40°.

Turnips when severely frozen became almost completely watersoaked both internally and externally. After the turnips were thawed at either 40° or 70° F., the external watersoaked areas became discolored and the internal areas became pithy. All except the most severely frozen turnips kept slightly better when thawed and held at 40° rather than at 70°.

INTRODUCTION

Fresh vegetables that have been injured by freezing are usually more susceptible to decay, inferior in quality, and poorer in appearance than vegetables that have not been frozen. When the frozen produce is handled properly, however, the damage or loss caused by the freezing can often be reduced or eliminated. An understanding of the nature of freezing and the prompt and accurate identification of the injury are essential before the proper handling practices can be employed.

Symptoms of freezing injury in some root crops have been described previously by Rose, et al.,[2] and by Harvey.[3] Rose and his coworkers generally tested a single freezing temperature near 20° F. and a single thawing temperature. No comparisons were made of injury at different freezing temperatures, or of the effects of rapid and slow thawing on the extent of injury. Harvey's research was limited to studies of ice formation in vegetables during freezing, and of the mechanical injury caused by the ice crystals.

The purpose of the studies reported here was to determine the effects of rapid and slow freezing and thawing on the overall quality of various root crops, and to identify, describe and illustrate the symptoms of freezing injury.

MATERIALS AND METHODS

Individual lots of fresh beets, carrots, parsnips, radishes, and turnips were purchased at the Washington, D. C., wholesale mar-

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[2] Rose, D. H., Wright, R. C., and Bratley, C. O. *Freezing injury of fruits and vegetables.* U. S. Dept. Agr. Cir. 713. 31 pp. 1944.

[3] Harvey, R. B. *Identification of freezing injury in fruits and vegetables.* Amer. Soc. Hort. Sci. Proc. 35:158–159. 1937.

ket for use in the tests. At the Beltsville, Md. laboratories of the U.S. Department of Agriculture, each lot was carefully examined and all vegetables with defects were discarded. Ten to twelve specimens of the vegetable in each lot were set aside for immediate use. The remainder was divided into 16 or 20 equal-size samples, depending upon the number of different freezing times that were to be used for the particular vegetable. All samples were held at 40° to 45° F. overnight.

The 10 to 12 specimens that were initially set aside were used to determine the time at which ice crystals began to form in the vegetable when placed at 20° or 0°F. This was accomplished by use of a copper-constantan thermocouple inserted ⅛ to ¼ inch into each of the vegetables. The electrical signals generated by the thermocouple were fed to a one-millivolt potentiometric strip-chart recorder with a 32° ice-water reference junction. At 32°, the zero potential of a copper-constantan thermocouple is zero. When the zero point was raised to read 50 on the 0 to 100 recorder scale, temperatures ranging from 8.4° to 55.0° could be continuously recorded. The temperature in each vegetable at the thermocouple was recorded until ice crystals formed. This point was indicated on the recorder chart by a sharp rise in temperature caused by the heat of crystallization which was liberated when the crystals formed (fig. 1). The average time required for ice crystals to form in each of the test vegetables at 0° and at 20° was then determined. The freezing times given in this report are computed from the time required for ice crystals to begin to form in each of the vegetables.

All the vegetables were frozen in 21-cubic-foot, chest-type freezers maintained at 0° or 20° F. Special thermostats installed in each freezer controlled the temperature within ±1° of the desired temperature. Carrots, beets, and turnips were frozen 1, 3, 6, and 24 hours at 0° and at 20°; parsnips were frozen 1, 3, and 6 hours at 0° and 20°; and radishes were frozen ¼, ½, 1, and 3 hours at 0° and 20°. The individual samples of each vegetable were placed in the freezers at predetermined intervals so that all samples, regardless of freezing times, could be removed simultaneously.

At removal, all vegetables were examined externally, and some were cut and examined internally. The remaining vegetables in each sample were divided into two subsamples, one of which was placed at 40° F. and the other at 70°. Relative humidity in both rooms ranged between 85 and 90 percent. Nonfrozen samples held at these temperatures served as checks. The vegetables in all sam-

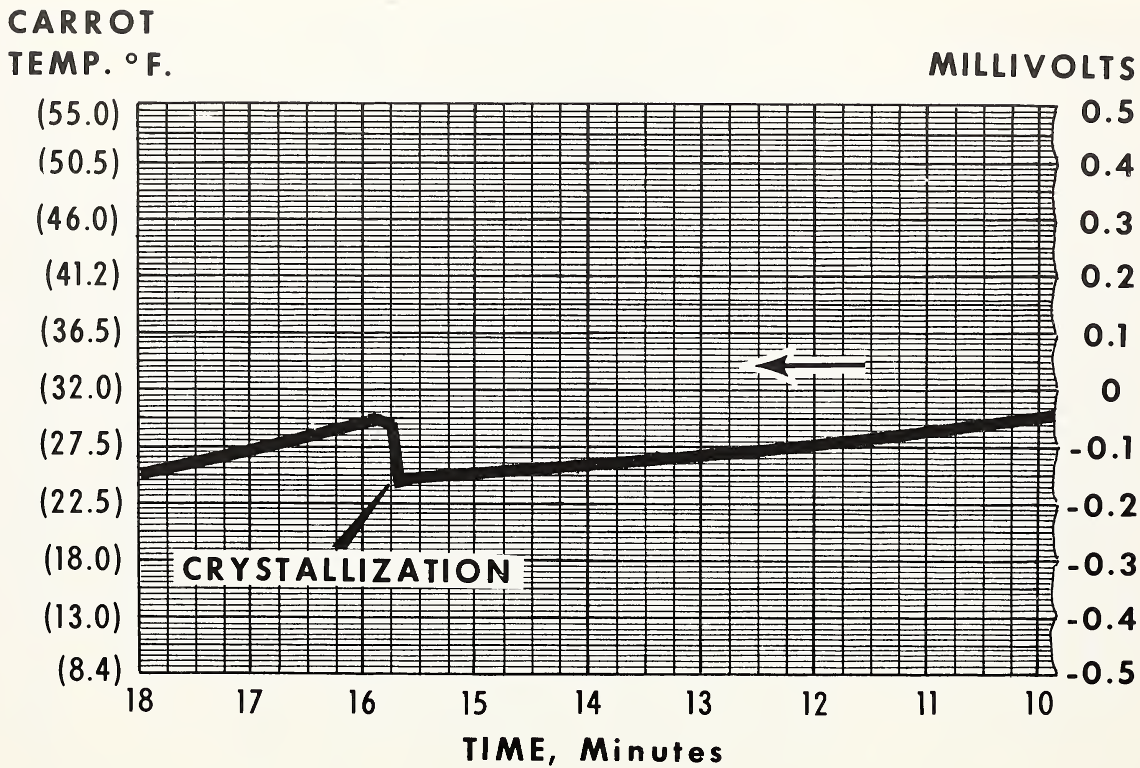


FIGURE 1.—Internal temperature of carrot held at 20° F. Chart is read from right to left. At about 15.7 minutes, when ice crystals formed within the carrot, the temperature in the carrot was increased suddenly by the heat liberated in crystallization.

ples were reexamined externally and internally after 1 day at 40° or at 70°. An additional examination of most vegetables was made after 2 days. Carrots were examined after 3 and 7 days. Samples of each crop were photographed to show freezing injury.

In some tests, weight loss was determined by carefully weighing the vegetable before freezing, immediately after freezing, and after holding at 40° and at 70° F.

In other tests, the respiration of frozen and nonfrozen vegetables was compared at 70° F. by placing weighed quantities in 5-gallon glass jars. Air was passed through the jars continually at five liters per hour and into an infrared carbon dioxide analyzer, where the percentage of carbon dioxide in each stream was determined.

RESULTS

Fruits and vegetables may be cooled to temperatures considerably below their freezing points before ice crystals form within the tissue. This phenomenon, known as undercooling, is observed only when the commodity is held perfectly still. The slightest jarring will often cause ice crystals to form instantly if the commodity temperature is at or below the freezing point. Freezing injury occurs in produce only after ice forms within the tissues. For this reason, extreme care should be exercised in handling produce after it has been cooled to temperatures near or below its freezing point, to prevent the formation of ice.

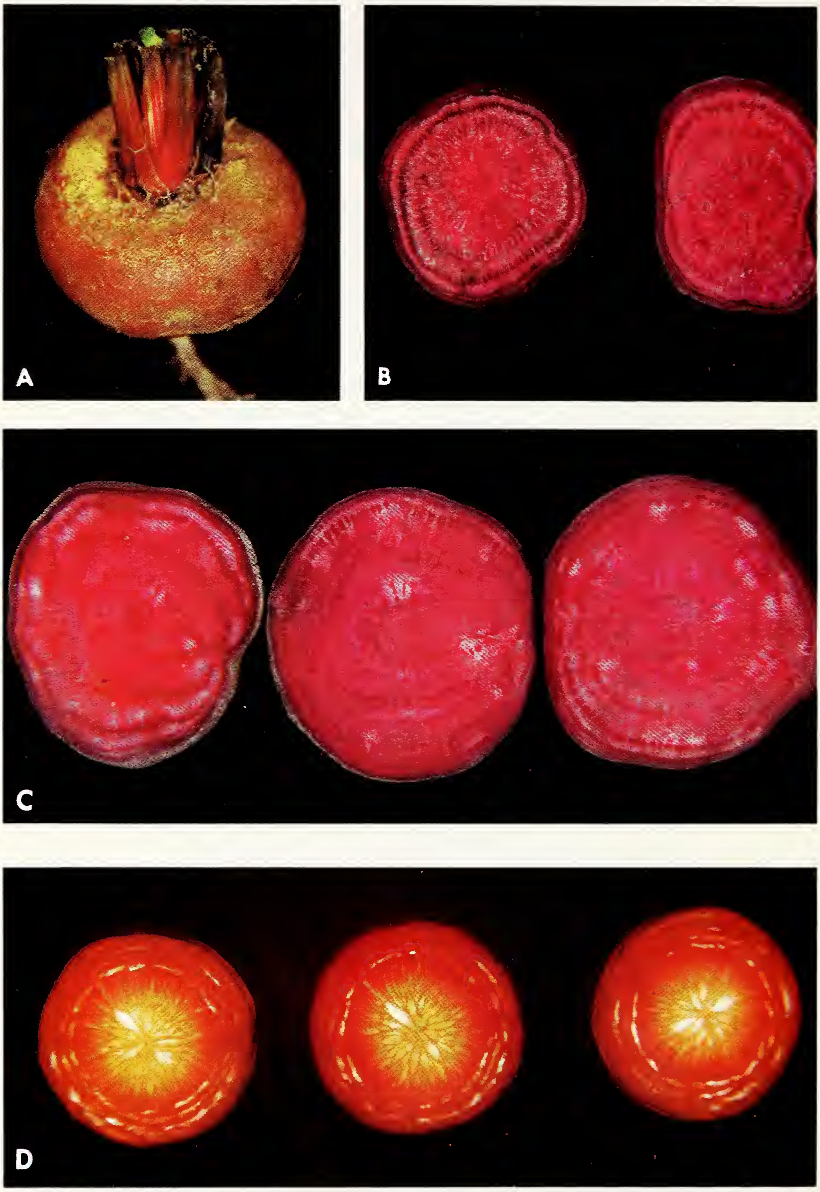
Beets

After Freezing

The only external symptom of injury on beets after slight freezing is a blackening of the stem remnants (plate 1A). The freezing point of beets ranges from about 29° to 30° F. Internally, the beets may exhibit darkened, watersoaked areas at their circumference, often in scattered spots rather than in a continuous band. When beets are severely frozen, dark watersoaked areas also are visible on the outer surface, and the internal watersoaking spreads to the center of the beet (fig. 2). When frozen this severely, beets generally lose a considerable amount of moisture during thawing and become soft.

After Thawing

Slight amounts of internal watersoaking observed in beets immediately after freezing very often disappeared during thawing



MRR 866, U.S. Dept. of Agriculture PLATE 1

A, Blackened stem remnants on beet frozen 1 hour at 20° F.; *B*, Blackened xylem rings in interior of beets frozen 3 hours at 0° F. and then stored 1 day at 40° or 70°; *C*, Internal appearance of beets frozen 1 hour at 20° F. and then stored 5 days at 70° F.; *D*, Ice crystals formed in carrots frozen 24 hours at 20° F.

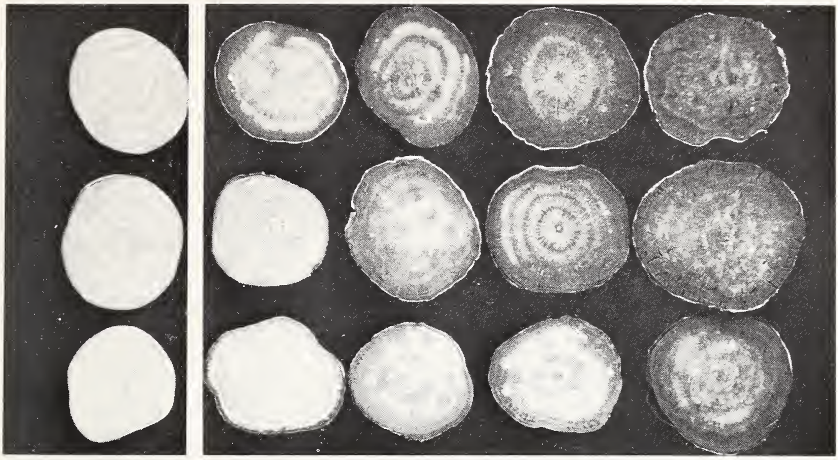


FIGURE 2.—Internal appearance of nonfrozen and previously frozen beets after being held 1 day at 70° F.

at 40° or 70° F. White patches sometimes appeared on the cut surfaces of slightly frozen beets after thawing (plate 1C). Larger areas of external and internal watersoaking in severely frozen beets persisted during and after thawing. Stem remnants, black and shrunken immediately after freezing, often became moldy in beets held 2 days at 70°, but not in those held 2 days at 40°.

Immediately after severely frozen beets had thawed, cell sap and melted ice crystals could easily be squeezed from cut tissue. The beets softened and became sticky or tacky, particularly when they were held at 70°. Xylem rings and rays of severely frozen beets exposed on cutting blackened rapidly at 70° (plate 1B).

Keeping Quality at 40° and 70° F.

Beets frozen 1 hour at 20° kept equally well at 40° and 70° for 2 days. Some trimming of stem remnants was necessary, but all remained salable. When beets were frozen 1 hour at 0°, a few remained salable after thawing 1 day at 70°, but none were salable when thawed at 40°. When frozen 3 or 6 hours at 0° or 20°, beets were soft, watersoaked, and unsalable when thawed at either 40° or 70°.

Frozen beets thawed at 40° F. tended to leak more water and cell sap than those thawed at 70°. Conversely, beets thawed at 70° became more "sticky" than those thawed at 40°.

Only slightly frozen beets are worth saving. They should be thawed and held at low temperatures to prevent possible loss from decay.

Carrots

Time of Freezing

When carrots were held in an undisturbed condition in the freezer at 0° F., the formation of ice crystals occurred first in the tips of the roots when they had undercooled to 22° (fig. 3). When the carrots were held at 20°, ice crystals did not form until the

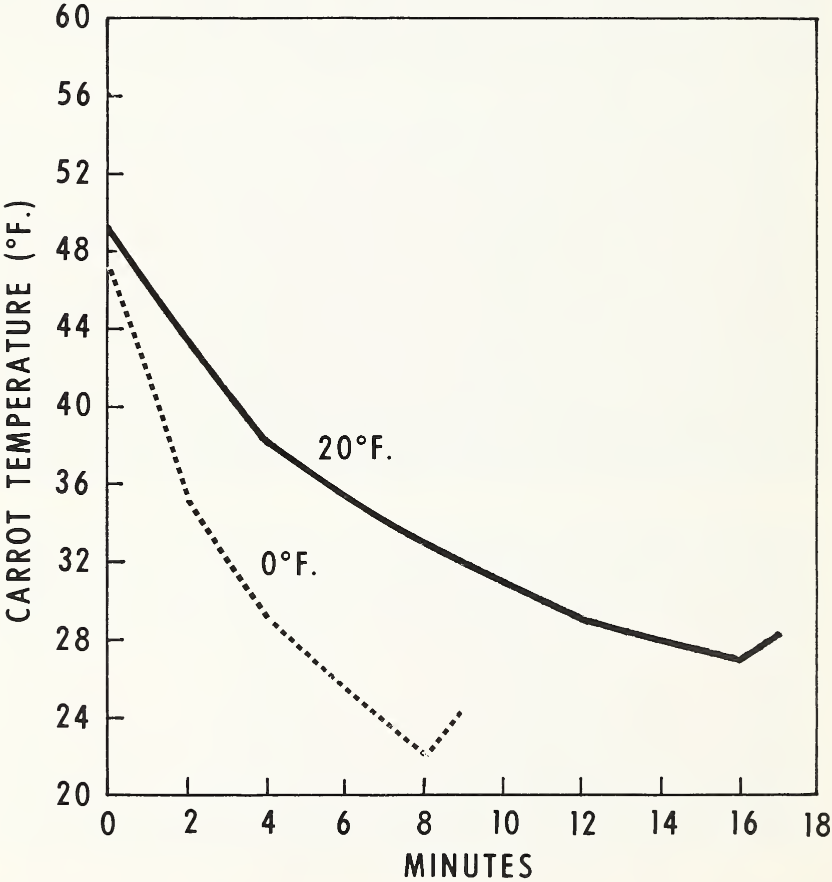


FIGURE 3.—Internal temperature of carrots held in an undisturbed condition at 0° F. and at 20° F., showing undercooling. The point at which ice crystals formed, indicated by the sudden rise in carrot temperature caused by the heat of crystallization, was from 2° to 7° lower than 29° F., the average freezing point of carrots.

carrots had undercooled to 27.2°. The average freezing point of carrots is about 29°.

Carrots at an average initial temperature of 48° F. began to freeze at the tips after only 8 minutes at 0°, and after 16 minutes at 20°. Freezing at the top and center of the carrots started 2 to 6 minutes later. If the carrots had been moved after they reached a temperature of 29° or below, ice crystals would have formed considerably sooner.

After Freezing

When carrots were held at freezing temperatures for prolonged periods, ice crystals initially formed around the circumference of the root. These could often be observed immediately after the carrots were removed from the freezing temperature. Later, as freezing continued, crystals also formed radially within the core of the carrot (plate 1D). The first visible crystals were formed after about 3 hours at 0° F. or 6 hours at 20°, depending upon the initial temperature of the carrots. Peripheral, lens-shaped crystals formed just beneath the surface often gave frozen carrots a "blistered" appearance immediately after freezing. No watersoaking was observed in carrots immediately after they were removed from the freezers.

A lengthwise cracking sometimes can be observed in carrots after they have been severely frozen (fig. 4). The jagged cracks usually are formed during the freezing process and not while the carrots are thawing. Cracks are observed most frequently in carrots that have been frozen 24 hours at 20° F. In our tests, they were less frequently observed in carrots frozen for shorter periods at 20°, or for periods up to 24 hours at 0°.

After Thawing

One of the principal symptoms of freezing injury in carrots is a dark brown or black appearance which develops on the surface of the root during thawing. The discoloration appeared only at the tips of slightly frozen carrots but covered the entire surface of severely frozen carrots (fig. 5).

Carrots subjected to severe freezing and then thawed at either 40° or 70° F. developed a darkened, watersoaked appearance internally and became soft and flabby (fig. 6). When the carrot was squeezed, liquid was easily expressed from the frozen tissue. The watersoaking usually was observed in carrots frozen 3 hours or longer at either 0° or 20° and then thawed.

When carrots have thawed completely, cracks formed by the expanded ice crystals are observed clearly in cut sections of the root (plate 2A). The peripheral cracks can be observed quite clearly when the carrot is bent.

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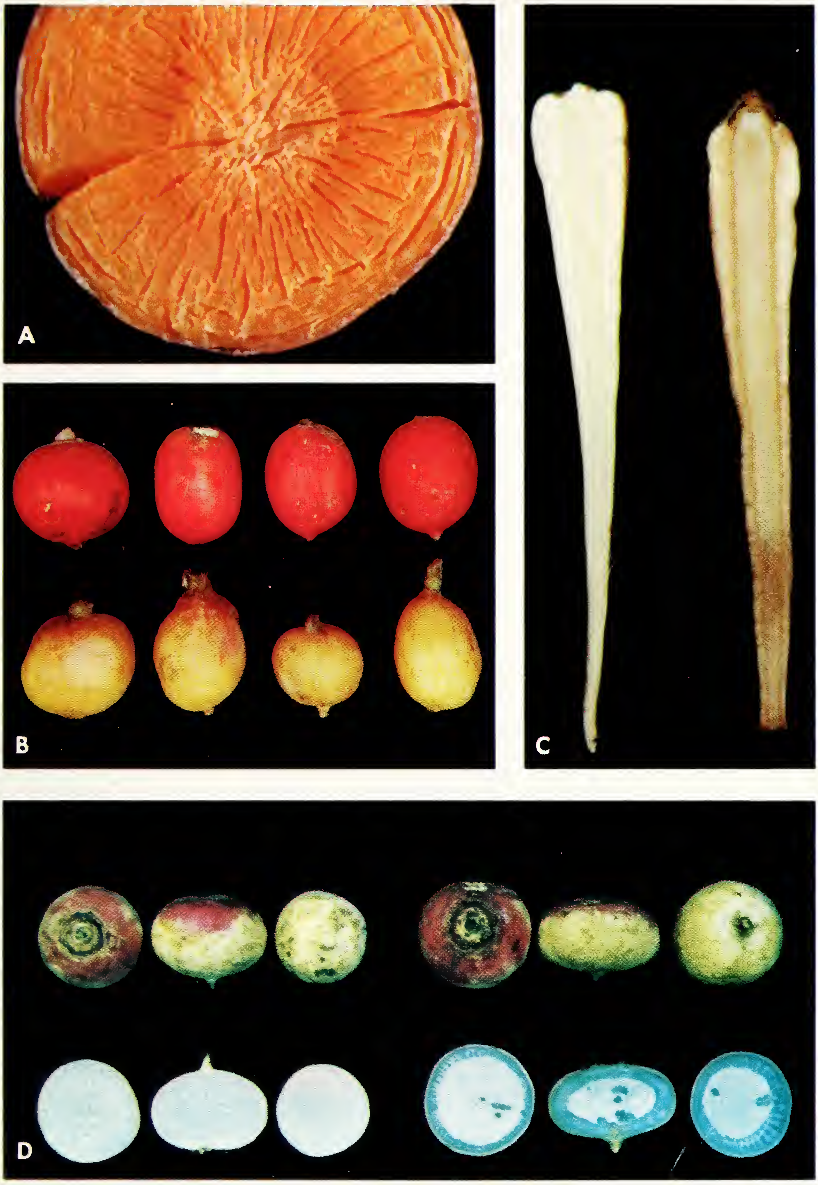
FIGURE 4.—Cracking in carrots frozen 24 hours at 20° F. and then held for 2 days at 40° F.



MRR 866, U.S. Dept. of Agriculture PLATE 2

A, Internal appearance of carrot frozen 24 hours at 20° F. and then held 2 days at 40° F.; *B*, External appearance of radishes after being held 3 days at 40° F. Nonfrozen radishes at top, radishes frozen 6 hours at 0° F. at bottom; *C*, Internal appearance of parsnips after being held 3 days at 40° F. Nonfrozen parsnip at left, parsnip frozen 6 hours at 0° F. at right; *D*, External and internal appearance of turnips after being held 2 days at 40° F. Nonfrozen turnips at left, turnips frozen 6 hours at 20° F. at right.

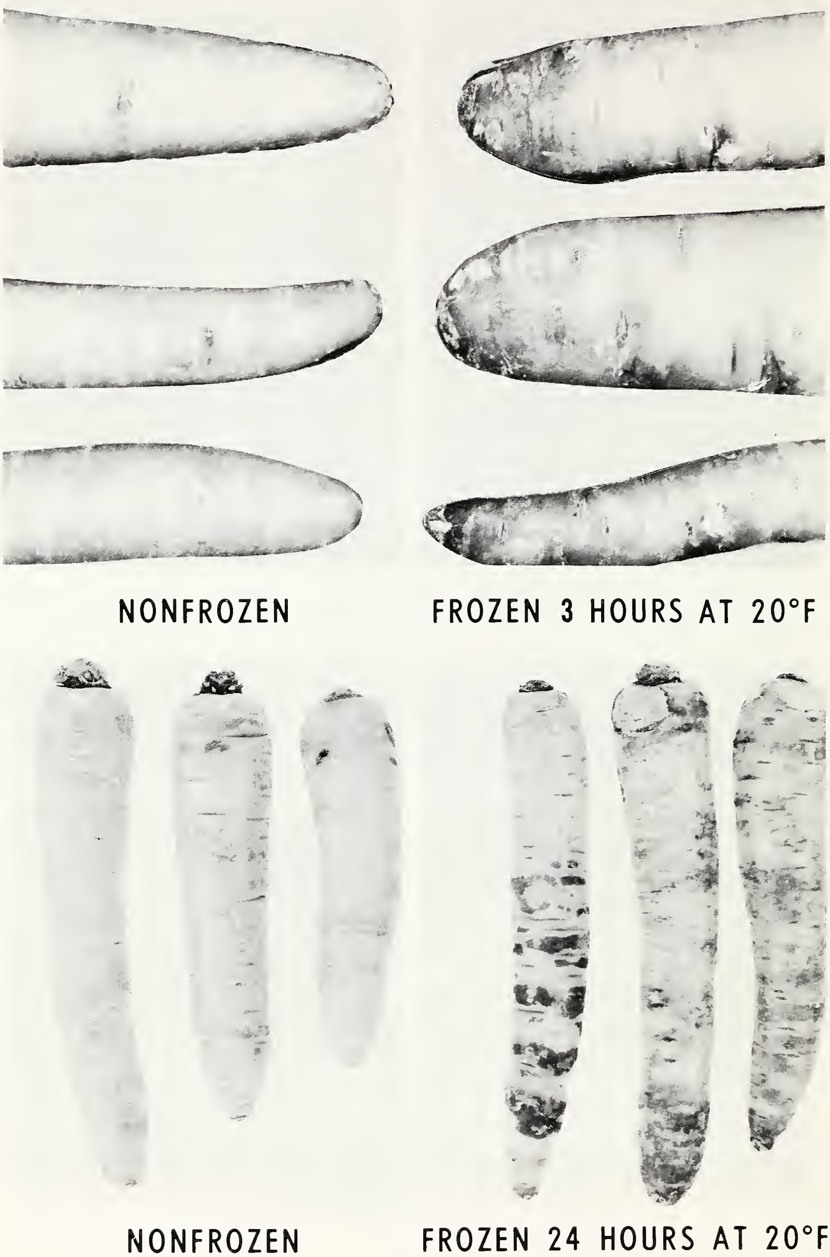


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FIGURE 5.—External appearance of nonfrozen and previously frozen carrots after being held for 2 days at 40° F.

NONFROZEN

FROZEN 24 HOURS AT 20°F.

BN-35921

FIGURE 6.—Internal appearance of nonfrozen and previously frozen carrots after being held for 2 days at 40° F.

Keeping Quality at 40° and 70° F.

Fresh fruits and vegetables, when frozen and then thawed, lose considerable weight, principally as moisture, and usually become soft and flabby. Carrots, for example, lost from 0.7 to 2.6 percent of their original weight during freezing at 0° or 20° F. for 1 to 6 hours (table 1). After freezing for 24 hours, the carrots lost 3.2 percent of their weight at 0° and 4.6 percent at 20°.

The ice crystals formed during freezing tend to rupture cell walls. The contents of these injured cells, together with the melting crystals, are rapidly lost from frozen produce during thawing. When thawed at 70° F., carrots frozen 1 to 24 hours at 0° or 20° lost 4 to 12 percent of their original weight in 1 day, and 10 to 20 percent in 3 days. Losses during the same periods at 40° averaged about half as great.

Slightly frozen carrots thawed at 40° F. discolored less than those thawed at 70°, while severely frozen carrots discolored badly at both temperatures. After 1 day at 70°, discoloration was observed in more than 60 percent of all carrots frozen 1 hour at 0°. After 1 day at 40°, only 12 percent of the carrots were discolored. Carrots frozen 6 or 24 hours at 0° were 100 percent discolored after 1 day at 40° or 70°.

TABLE 1.—*Weight loss during freezing and storage of carrots*

Freezing		Weight loss during freezing	Weight loss after freezing and storage for—			
			1 day at—		3 days at—	
Temperature	Time		40° F.	70° F.	40° F.	70° F.
°F.	*Hours*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	0	0	2.0	4.1	4.8	10.1
0	1	0.9	2.1	5.7	4.7	13.1
0	3	1.8	2.1	4.4	4.5	13.7
0	6	2.6	4.6	4.9	6.6	17.0
0	24	3.2	7.1	12.3	10.8	19.8
20	0	0	2.2	4.6	4.7	7.2
20	1	0.7	2.2	4.3	4.6	7.0
20	3	1.6	2.4	4.8	5.1	11.5
20	6	2.6	2.6	4.9	5.7	12.9
20	24	4.6	4.7	6.4	6.4	15.0

Watersoaking was more prevalent in severely frozen carrots thawed at 40° F. than in similarly frozen carrots thawed at 70°.

Frozen fruits and vegetables are often highly susceptible to decay after thawing. The amount of decay depends upon the severity of the freezing and upon the temperature at which frozen commodities are held.

Carrots frozen 1 hour at 20° F. and held at 70° were not decayed after 1 or 3 days, but, by the seventh day, 8 percent were decayed (table 2). Carrots frozen 3, 6, or 24 hours at 20° showed a considerable amount of decay after 3 and 7 days at 70°. When the frozen carrots were held at 40°, none decayed in 1 or 3 days, and only those frozen 24 hours showed slight decay on the seventh day.

Carrots frozen at 0° F. decayed much more rapidly than carrots frozen similar periods of time at 20°. After 3 days at 70°, carrots frozen 1 hour at 20° showed no sign of decay but carrots frozen 1 hour at 0° were 50 percent decayed. Almost all carrots frozen 3 hours or longer at 0° were decayed after 3 days at 70°.

Respiration

Slight injury in one form or another tends to stimulate respiration of fresh produce, while severe injury often depresses it. In these tests, carrots frozen for 1 or 3 hours at 0° F. respired greater amounts of carbon dioxide at 70°, on the average, than nonfrozen carrots (fig. 7). During the first few hours at 70° after freezing, a low carbon dioxide production rate by carrots appar-

TABLE 2.—*Decay of carrots held 1, 3, or 7 days at 40° or 70° F. following freezing for various periods at 20°*

Period of freezing	Storage temperature	Decayed carrots after— 1 day	3 days	7 days
Hours	*°F.*	*Percent*	*Percent*	*Percent*
0	70	0	0	0
1	70	0	0	8.3
3	70	0	20.8	25.0
6	70	0	45.8	66.7
24	70	0	91.7	95.8
0	40	0	0	0
1	40	0	0	0
3	40	0	0	0
6	40	0	0	0
24	40	0	0	12.5

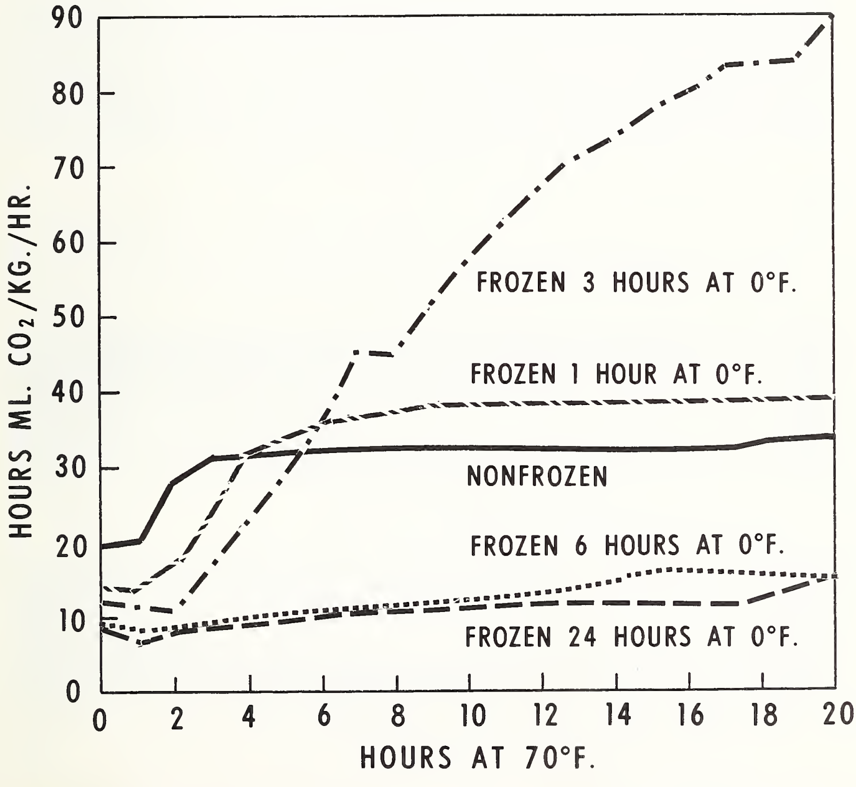

FIGURE 7.—Effect of previous freezing periods on respiration of carrots while they are being held at 70° F.

ently was due to the presence of ice crystals in the tissue. After 15 hours at 70°, carrots which had been frozen 1 hour at 0° were thawed completely and respiring about 15 percent more rapidly than nonfrozen carrots. After the same period, carrots that had been frozen 3 hours at 0° were respiring more than twice as rapidly as nonfrozen carrots.

Severe freezing, which kills many cells, tends to reduce the respiration of plant tissue. Carrots frozen 6 or 24 hours at 0° F., for example, respired less than half as much carbon dioxide as nonfrozen carrots during a 20-hour holding period at 70°.

Parsnips

After Freezing

Parsnips may be subjected to a considerable amount of freezing without lasting damage. When moved from 50° to 20° F., parsnips became partly frozen in 3 hours and solidly frozen in 6 hours. No external discoloration appeared on any of the parsnips and only those solidly frozen were affected internally. The center or core of these parsnips was watersoaked and darker than normal (fig. 8). Parsnips moved from 50° to 0° became solidly frozen in 3 hours and were watersoaked internally.

After Thawing

After thawing at 70° F. for 24 hours, parsnips frozen at 0° or 20° for periods up to 3 hours showed very little sign of damage.

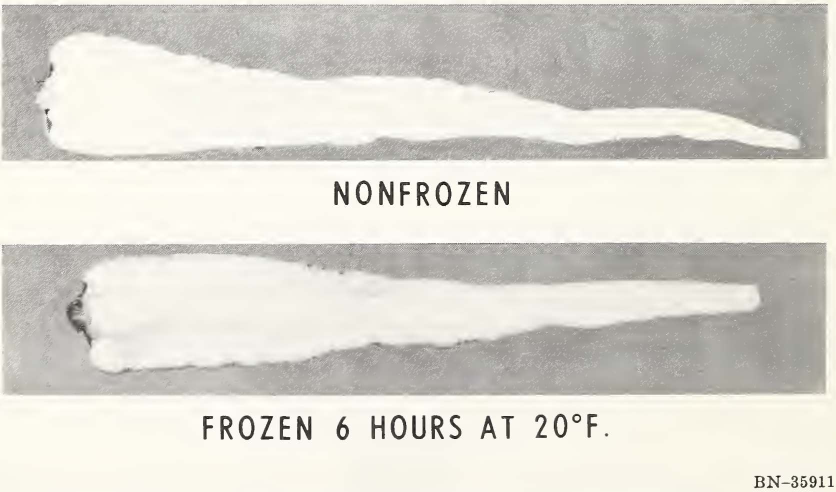

Figure 8.—Internal appearance of nonfrozen and previously frozen parsnips.

The tips of the parsnips were discolored and shriveled, and the entire root was slightly soft, but most of them would be salable without a discount. After severe freezing, such as 6 hours at 0°, parsnips held at 70° for 24 hours became soft, tacky, and dark brown (fig. 9). Internally, a reddish-brown area developed in the cambium region of severely frozen parsnips when stored at either 40° or 70°, and the roots were completely watersoaked (plate 2C). Parsnips frozen this severely would not be salable.

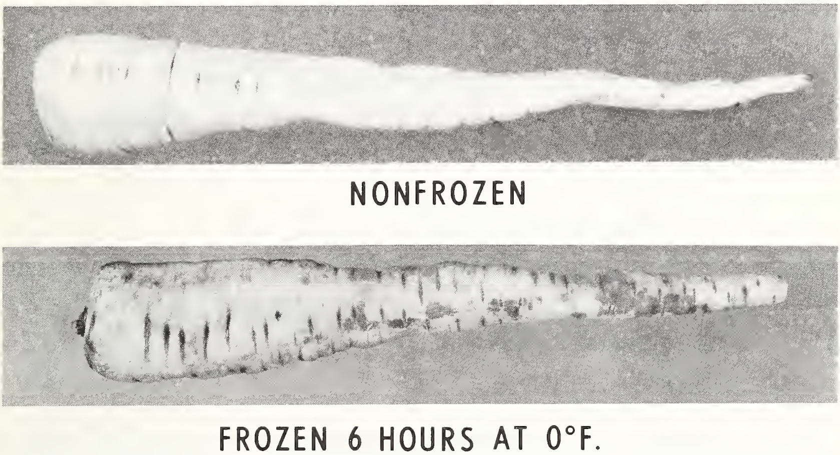

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FIGURE 9.—External appearance of nonfrozen and previously frozen parsnips after they have been held for 24 hours at 70° F.

Keeping Quality at 40° and 70° F.

Previously frozen parsnips generally remained in better condition during holding at 40° than during holding at 70°. After 2 days at 70°, parsnips previously frozen 3 or 6 hours at 0° or 20° became flabby, wrinkled, and unsalable. At 40°, the parsnips remained firm, and most were salable except those frozen 6 hours at 0°. At 40°, softening and tackiness were reduced or eliminated. Most parsnips that had not been solidly frozen recovered and were salable with very little trimming.

Radishes

After Freezing

Injury in radishes due to freezing can be recognized most readily by the watersoaked areas that occur in frozen specimens.

BN-35912

FIGURE 10.—Internal watersoaking in slightly frozen radish.

These areas, dull and slightly darker than normal, begin to appear when ice crystals form within the radish. Crystals can form in less than 15 minutes when radishes are exposed to temperatures below 20° F. The watersoaking, initially present in small, isolated spots, spreads gradually over the entire surface if the freezing is continued. The tap root of the radish is often the first area to show watersoaking because of its relatively small girth.

Watersoaking also may occur internally in frozen radishes. It is characterized by a general clearness of the flesh (fig. 10). This clearness or translucence is restricted to areas just beneath the surface of the root in slightly frozen specimens but encompasses the entire root when the radish is frozen severely (fig. 11).

Radishes frozen severely often feel rough or pebbly immediately after freezing because of the ice crystals formed directly beneath the surface.

After Thawing

The most common symptoms of freezing injury in radishes after thawing are increased shriveling, softening, and decay. Shriveling, which can occur in nonfrozen radishes held 1 day or longer at 70° F., is greatly intensified by freezing (fig. 12). In

these tests, shriveling was observed, after 1 day at 70°, in 20 percent of the nonfrozen radishes and in 68 percent of the radishes frozen 15 minutes at 0°. Shriveling was not observed in nonfrozen radishes held at 40° for 1 or 2 days but was observed in all frozen radishes stored the same periods.

Radishes severely frozen lose moisture rapidly during thawing and become soft. The percentage of soft radishes in a frozen lot will depend more on the freezing time and temperature than on the thawing temperature. Once the freezing has occurred, little can be done to reduce the number of soft radishes that will be present after thawing. Moisture lost from severely frozen radishes often carries with it much of the red pigments from the surface cells, leaving the thawed radishes with a bleached appearance (plate 2B).

Keeping Quality at 40° and 70° F.

The salability of radishes, once frozen, diminishes rapidly. Radishes frozen at 20° for only 15 minutes were 85 percent salable after 1 day at 70° but only 43 percent salable after 2 days. When radishes were frozen 15 minutes at 0° instead of 20°, their

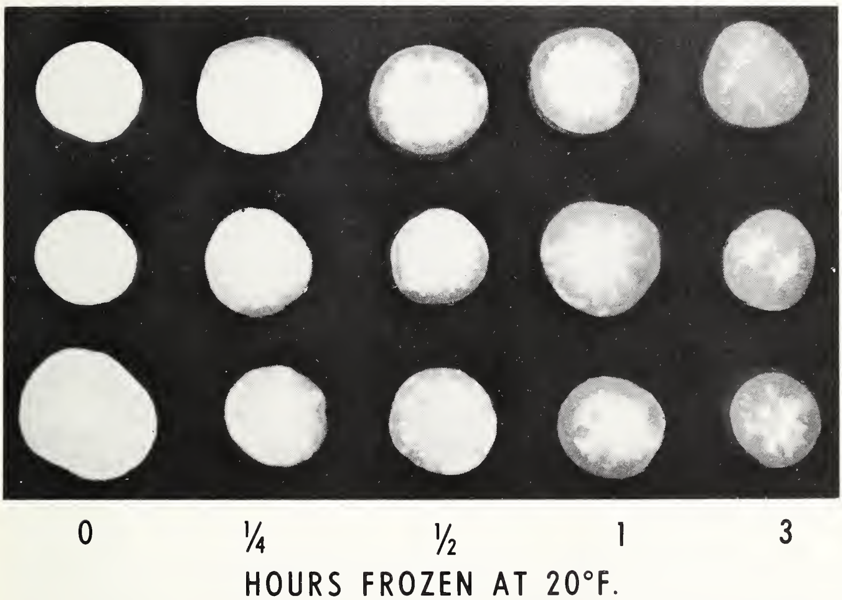

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FIGURE 11.—Internal watersoaking in nonfrozen and previously frozen radishes.

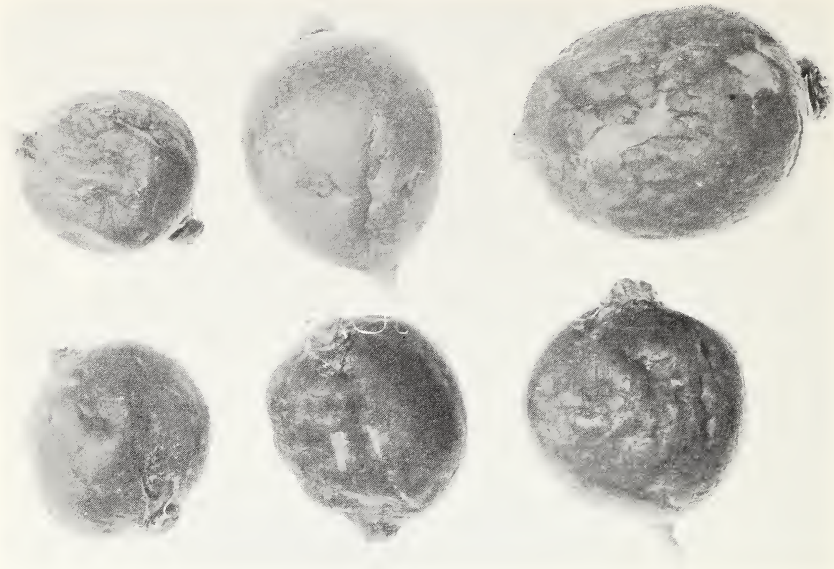

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FIGURE 12.—Shriveling in radishes frozen 1 hour at 20° F. and then held 1 day at 70° F.

salability after 1 and 2 days at 70° dropped to 22 percent and 12 percent, respectively.

Shriveling was more common in radishes held at 70°, while internal and external watersoaking were more common at 40°. When held 2 days after freezing, radishes at 40° were definitely better than those at 70° because of reduced decay. After 2 days, for instance, radishes that had been frozen 15 minutes at 20° were 83 percent salable at 40° but only 43 percent salable at 70°.

When radishes were frozen 1 hour at 20° F., they remained about 50 percent salable after 1 day at either 40° or 70°. When frozen the same period at 0°, or longer periods at either temperature, the radishes were worthless when removed from the freezer.

Turnips

Time of Freezing

The time required for the formation of ice crystals in turnips and other vegetables is determined by initial product temperature and by the temperature at which the vegetables are frozen. After being moved from 45° to 20° F., for example, turnips showed the first signs of freezing after an average of 27 minutes. When

moved from 45° to 0°, freezing began after an average of only 3 minutes. These freezing times were determined while the turnips remained undisturbed during the cooling and freezing period. Any sharp movement after the turnips had reached their freezing point would have shortened the freezing times considerably.

After Freezing

A characteristic symptom of freezing injury in turnips is internal and external watersoaking (plate 2D). The external watersoaking appears initially in small, circular spots on the fleshy part of the root. As freezing progresses, the spots gradually coalesce to form continuous watersoaked areas, which eventually cover the entire root.

Internal watersoaking is present in turnips immediately after freezing and can be identified by patches of gray or translucent flesh (fig. 13). These patches lie both inside and outside the cambium but are principally inside. As the severity of freezing increases, the watersoaked areas become continuous around the circumference of the turnip. The depth to which the watersoaking progresses into the flesh is determined by the severity of the freezing (fig. 14).

The surface of severely frozen turnips often is "blistered" due

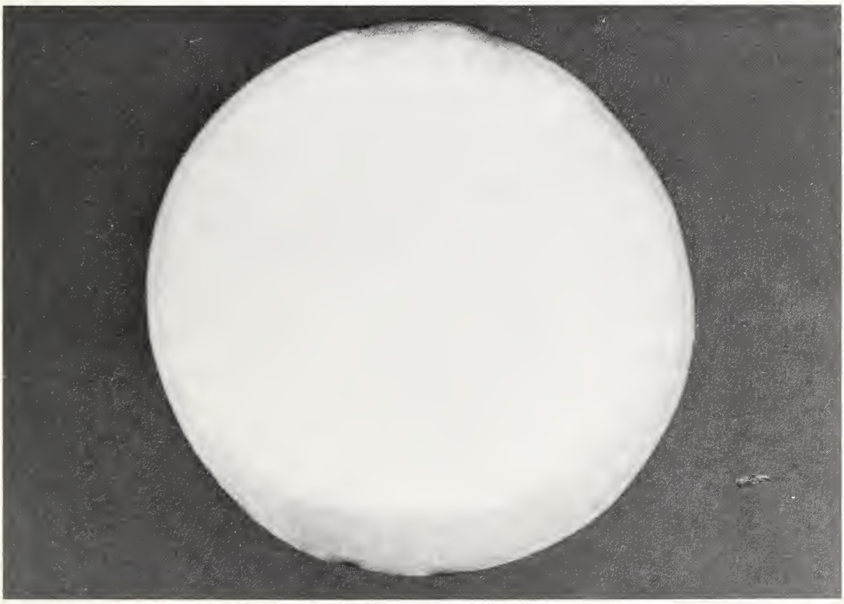

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FIGURE 13.—Internal watersoaking in a turnip frozen 1 hour at 20° F.

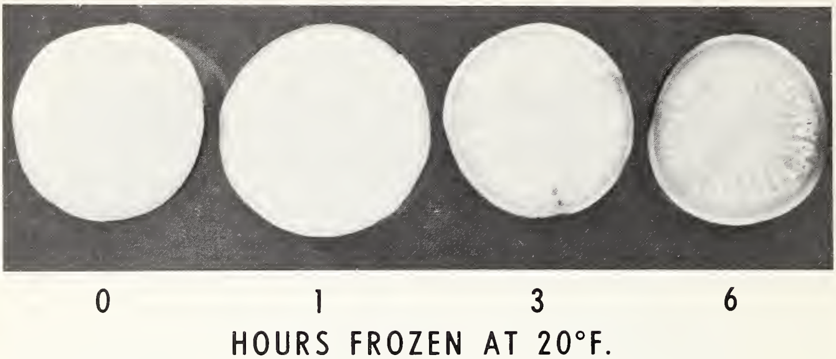

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FIGURE 14.—Internal watersoaking in nonfrozen and previously frozen turnips.

to ice crystals formed between the periderm and the flesh. This blistering usually can be observed ½ to 1 hour after turnips are placed at either 0° or 20° F.

Slender tap roots often are frozen solid during short periods at freezing temperatures because of their relatively small girth.

After Thawing

After frozen turnips are thawed, they become soft and flabby due to a loss of moisture. This softening and flabbiness is most obvious in the slender tap root. It is more severe in turnips frozen at 0° F. than in turnips frozen similar periods at 20°.

Internal and external watersoaking remain visible in severely frozen turnips stored at either 40° or 70° F. for 1 or 2 days. The external watersoaking appears tan or gray, and the turnips have a nauseating and fermented odor. Watersoaking in slightly frozen turnips tends to disappear during thawing at either 40° or 70°. When this occurs, the watersoaked areas just inside the cambium often become pithy.

Pitting may occur in turnips following freezing and thawing (fig. 15). Frequently, it was observed in turnips frozen 3 and 6 hours at 20° F., or 1 and 3 hours at 0°. It was seldom observed in turnips frozen for shorter periods at these temperatures. In turnips frozen 6 or more hours at 0°, or 24 hours at 20°, decay or shriveling during storage tended to obscure any pitting that may have occurred.

Keeping Quality at 40° and 70° F.

Turnips frozen for as long as 3 hours, at either 0° or 20° F.,

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FIGURE 15.—Surface pitting in a turnip frozen 6 hours at 20° F. and then held 1 day at 70° F.

remained in better condition following thawing at 40° than following thawing at 70°. Turnips frozen for longer periods deteriorated rapidly at both temperatures.

Softening, due to loss of moisture, of frozen turnips during subsequent storage was more severe when thawed at 70° F. than when thawed at 40°. After 2 days, turnips frozen 1 hour at either 0° or 20° had softened slightly at 70° but remained very firm at 40°. After the same holding period, turnips frozen 3 hours at 0° were moderately soft or spongy at 70° but were still firm at 40.°

Surface pitting was more severe in frozen turnips thawed at 70° F. than in those thawed at 40°. For example, pitting was observed in almost 50 percent of turnips frozen 6 hours at 20° and then held 1 week at 70°. When the turnips were held 1 week at 40°, only 15 percent of them showed pitting.

Respiration

The effect of freezing on subsequent respiration of turnips at 40° and 70° F. is shown in figure 16. After 8 hours at 70°, turnips that had been frozen 1 hour at 0° were respiring twice as rapidly as nonfrozen turnips and after 20 hours about 70 percent

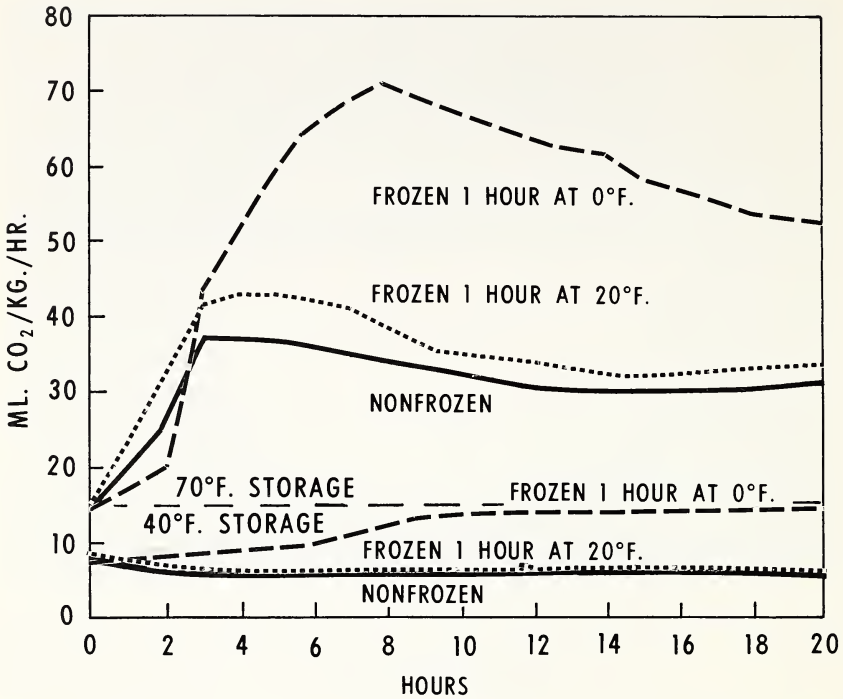

Figure 16.—Effect of previous freezing periods on respiration of turnips while they are being held at 40° F. or at 70° F.

more rapidly. When freezing was less severe (1 hour at 20°) turnips respired about 10 percent more rapidly than nonfrozen samples. Turnips frozen 1 hour at 0° and then thawed at 40° also respired about twice as rapidly at 40° as nonfrozen turnips. Freezing turnips 1 hour at 20° did not appreciably change the respiration rate at 40°, as compared to that of nonfrozen turnips.

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